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# Is it efficient to discriminate passengers in airport charges according to flight distance?

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## Abstract

This paper examines the pricing strategy of private airports. To capture the relationship between airport fees and airport locations, we develop a model with the asymmetric hub-spoke network. We obtain the following results. First, spoke airports which are far from the hub set their airport fees low. Second, the hub airport offers a large discount for transit passengers when the average distance between the hub and spokes is long. Finally, when all cities possess the same population, the policy maker can improve social welfare by allowing the hub to discriminate transit passengers in the setting of airport fees.

**Keywords:** Airport Pricing, Hub–Spoke Network, Asymmetric Network, Price Discrimination, Private Airports, Transit Passengers

**JEL classification:** R48 (Government Pricing and Policy), L93 (Air Transportation)

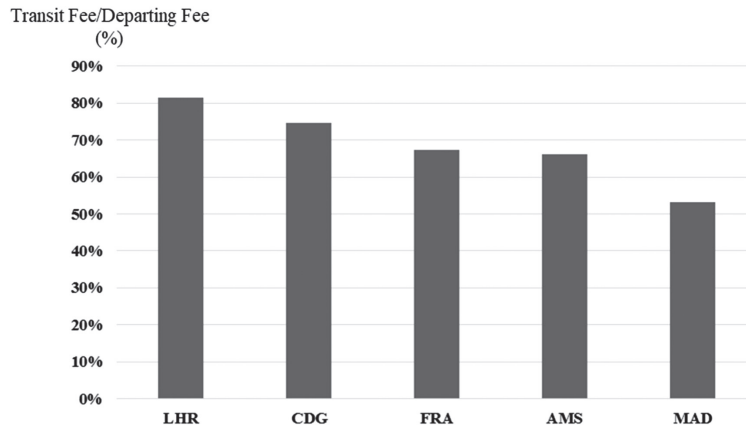
## 1. Introduction

After the liberalization in the aviation industry, the networks of airlines changed from the point-to-point to the hub-spoke design. As a result, passengers departing from airports at a spoke node (spoke airport) now have to transit at a hub when they travel. This transit at the hub imposes some additional costs on passengers from spoke airports. Therefore, transit passengers incur larger trip cost than those departing from hub airports. The cost related to the transit may include the airport fee payment; that is, transit passengers have to pay the airport fees at the departing spoke and hub airports. However, hub airport operators offer a discounted fee for transit passengers. Figure 1 summarizes the ratio of the discounted transit airport fee against the departing airport fee for the five largest airports in Europe in 2011: London Heathrow (LHR), Charles de Gaulle (CDG), Frankfurt (FRA), Amsterdam (AMS) and Madrid (MAD). In Figure 1, the degree of the discount differs among these five airports: LHR offers the highest transit fee, 82% of the departing fee, while MAD offers the lowest, 53% of the departing fee. Here, the fees include both airline fees (landing fees, noise charges and parking charges) and passenger fees (the Passenger Service Facility Charge (PSFC) and Passenger Security Service Charge (PSSC)). The object of discount is the latter.

The formation of the hub-spoke network may also affect the spoke airport fee. Figure 2 shows

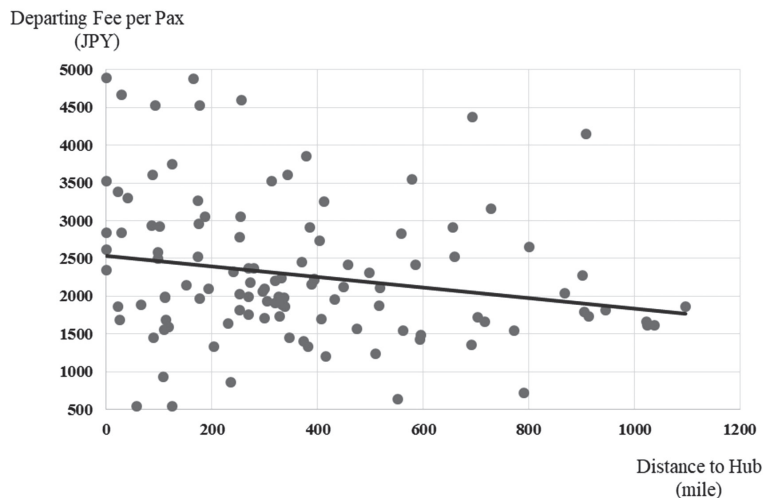
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the relationship between the fee of European airports and the minimal distance to the five largest airports in Europe: LHR, CDG, FRA, AMS, and MAD. Each dot represents an European airport with more than one million passengers in 2011, while the bold line in Figure 2 represents the fitted line. The fitted line may suggest that the airport fee decreases as the minimal distance to the major hubs increases. This paper aims to clarify the mechanisms of the data presented in Figures 1 and 2; that is, (i) why do spoke airports, which are farther from the hubs, set their airport fees lower and (ii) what is the determinant of the discount rate for the transit passengers offered by hub airports?



**Figure 1: The ratio of the transit fee against the departing fee\***

\*This figure compares the fees of departing and transit passengers from a B787 passenger jet (280 seats). To compute the fees, we use the IATA Airport, ATC and Fuel Charges Monitor (IATA, 2013) and set several assumptions: the aircraft utilises the parking for three hours during the daytime; the loading factor is 71%; and the MTOW (Maximum Takeoff Weight) is 301 t.



**Figure 2: The relationship between the airport fee and the distance to the hub\***

\*: This figure demonstrates the departing fees for passengers boarding a B787 passenger jet (280 seats) for European international airports, which are appeared in the IATA Airport, ATC and Fuel Charges Monitor (IATA, 2013). In computing the airport charges, we set the same assumptions as in Figure1.

Focusing on the relationship between airports, by its nature, the services provided by airports may become the substitute or the complementary goods. In case of the substitute goods, airports compete for passengers from the common catchment area; therefore, the airport fees become the strategic complements (for example, Czerny et al. (2014) and Teraji and Morimoto (2014)).<sup>1</sup> When passengers utilize a pair of airports as the origin and destination, the airport services are the complementary goods. In such case, the airport fees become the strategic substitutes (Mantin (2012) and Matsumura and Matsushima (2012)).<sup>2</sup> In order to explain the mechanism behind Figures 1 and 2, we employ the second approach: namely, the airports are the complementary goods.

In terms of network structures, most papers that focus on airports in complementary goods relationship consider a network with one hub airport and two spoke airports. Based on this network, Lin (2013) treated pricing strategy of privatized airport to analyze airport congestion problem. Brueckner (2005) expanded the network to two hub airports and two spoke airports in order to capture decisions of network carriers. However, this type of networks has a problem that it is impossible to analyze effects of distance between airports on pricing strategy. Oum et.al. (1996) established a model of network with one hub airport and arbitrary number of spoke airports. Kawasaki (2014) applied this network for relationship among international hub and domestic spoke airports. However, their network structures are symmetric and distances from spoke airports to the hub are the same.

This paper also based on the network of Oum et.al. (1996) and improved it to “asymmetric” structure. That is, spoke airports locate at an arbitrary distance from the hub. Using this model, we analyze how distance between the hub and spoke airports affects airport charges.

The rest of this paper is organized as follows. In Section 2, we describe the model, which is used to clarify the reason why spoke airports that are farther from the hubs set their airport fees lower and what affects the discount rate for the transit passengers at hub airports. In Section 3, we solve the game among airports and compare the analytical results with some stylized facts described above. In Section 4, we derive the welfare effect for each spoke market and analyse how the distance to the hub affects the welfare loss of each market. In Section 5, we suggest the discriminatory pricing policy to improve the social welfare. Finally, Section 6 states concluding remarks.

## 2. The Model

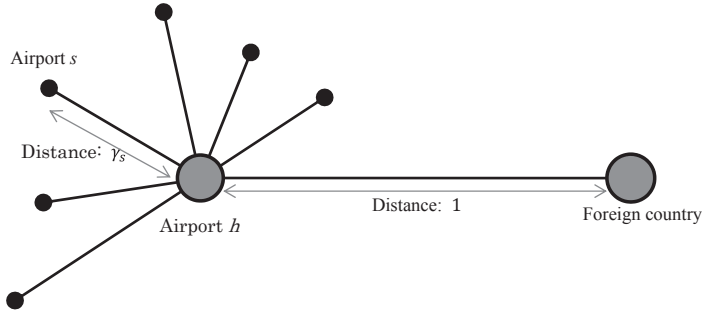
Let us consider a situation in which an airline connects  $S+1$  airports with a foreign country by forming a hub-spoke network as shown in Figure 3.<sup>3</sup> In Figure 3,  $\gamma_s$  represents the distance between the hub and each spoke  $s$ , and we normalize the distance between the hub and foreign country to 1. Hereafter, we refer to the hub airport as *Airport h*, each spoke airport as *Airport s* ( $s=1,2,\dots,S$ ), and *City i* ( $i=h$  and  $1,2,\dots,S$ ) is the city in which *Airport i* is located. The population of *City i* is represented by  $n_i$  and we normalize the population of *City h* to 1,  $n_h = 1$ .

<sup>1</sup> Czerny et al. (2014) focused on the case where the two ports compete for the demand from the third region and evaluate the welfare effects of the port privatization. Teraji and Morimoto (2014) dealt with the competition of airports to become a regional hub. In their model, two airports locate in a same country and compete for the international trip demand from the country.

<sup>2</sup> Similar to Czerny et al. (2014), Mantin (2012) and Matsumura and Matsushima (2012) evaluated the welfare effects of the airport privatization. Different from Czerny et al. (2014), however, they dealt with the situation where the two airports constitute the origin-destination pair.

<sup>3</sup> Long-haul flights from *Airport h* to the foreign country represent flights such as those from Europe to Asia or to the United States.

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**Figure 3: Hub-Spoke Network**

The economy has three agents: the airports, the airline, and consumers. The sequence of decisions among these agents is as follows. First, all airports set their airport fees simultaneously to maximize their revenue. Second, the airline sets its fares to maximize its profit. Finally, consumers in each city decide their demand for flights to the foreign country. Hereafter, we trace the decision-making process.

The demand for air services is

$$d_h = 1 - p_h - a_d \quad (1.1)$$

$$d_s = n_s(1 - p_s - a_t - a_s) \text{ for } s = 1, 2, \dots, S, \quad (1.2)$$

where  $p_i$  denotes the airfare.  $a_d$  and  $a_t$  denote the airport fees of the hub for the departing passengers and for the transit passengers, respectively. We call the former “departing fee” and the latter “transit fee.” In (1.2),  $a_s$  is the airport fee of a spoke airport. Hereafter, we refer to passengers departing from *Airport h* as “hub passengers” and passengers departing from *Airport s* as “spoke passengers.”

The airline creates the hub-spoke network and provides two types of flights, connecting flights between *Airport h* and each spoke airport, and direct flights between *Airport h* and the foreign country. We assume that the airline’s operating cost is proportional to the passenger-kilometer. Specifically, operating cost per passenger is  $c\gamma_s$  for the connecting flight and  $c$  for the direct flight. The total operating cost is

$$C = cd_h + \sum_{s=1}^S (1 + \gamma_s)cd_s. \quad (2)$$

The first term is the operating cost for shipping hub passengers and the second term is the operating cost for shipping spoke passengers. Here, we assume that the airline does not pay airport fees. In reality, while airlines pay airport fees such as landing, aircraft parking and handling fees, they are shifted onto passengers through the airfare. Therefore, the equilibrium demand and social welfare are given just as functions of total airport fees (= the sum of all the fees levied by airport operators). Therefore, in our model, only passengers pay airport fees. Similar assumptions are used in Oum et al. (1996) and Kawasaki (2014).

Using (2), we obtain the airline’s profit as

$$\pi = (p_h - c)d_h + \sum_{s=1}^S [p_s - (1 + \gamma_s)c]d_s. \quad (3)$$

The first term is the profit from hub passengers and the second term is the profit from spoke passengers. The airline sets its airfare to maximize profit:

$$\max_{p_i} \pi. \quad (4)$$

Each airport levies airport fees on passengers. Total fee revenue is computed as

$$R_h = a_d d_h + a_t \sum_{s=1}^S d_s \quad (5.1)$$

$$R_s = a_s d_s \quad (5.2)$$

The first term of (5.1) is the revenue from hub passengers and the second term is from spoke passengers. We ignore airports' operating cost; therefore, private airports set their airport fees to maximize their fee revenue, that is,  $\max_{a_d, a_t} R_h$  for the hub and  $\max_{a_s} R_s$  for the spokes.

### 3. Equilibrium

This section derives the equilibrium airport fees in the hub-spoke network. Furthermore, we verify the stylized facts given in Figures 1 and 2; specifically, whether the distance to the hub affects the airport fees of each spoke airport and whether the hub operator reduces its transit fee as the network size expands. Subsection 3.1 derives the airfares and the demand whereas Subsection 3.2 solves the game among airports. Finally, Subsection 3.3 uses these solutions to check if the two stylized facts work in our setting.

#### 3.1. The Airline's Choice

By solving the airline's profit maximization problem, we obtain the equilibrium airfares:

$$p_h = \frac{1 + c - a_d}{2}, \quad (6.1)$$

$$p_s = \frac{1 + (1 + \gamma_s)c - a_t - a_s}{2}. \quad (6.2)$$

Substituting these two equations into (1), we rewrite the demand as a function of airport fees,  $a_d$ ,  $a_t$ , and  $a_s$ :

$$d_h = \frac{1 - c - a_d}{2}, \quad (7.1)$$

$$d_s = \frac{n_s[1 - (1 + \gamma_s)c - a_t - a_s]}{2}. \quad (7.2)$$

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Hereafter, we assume that all spoke routes have the positive potential demand:

$$1 - c(1 + \gamma_s) > 0 \text{ for } s = 1, \dots, S.$$

### 3.2. Equilibrium Airport Fees

Solving each airport's revenue maximizing problem, we obtain the best response functions as follows:

$$a_d = \frac{1 - c}{2}, \quad (8.1)$$

$$a_t(a_1, \dots, a_s) = \frac{1 - c}{2} - \frac{1}{2} \left( c\bar{\gamma} + \frac{\sum_{s=1}^S a_s n_s}{\sum_{s=1}^S n_s} \right), \quad (8.2)$$

$$a_s(a_t) = \frac{1 - (1 + \gamma_s)c - a_t}{2} \quad (8.3)$$

Here,  $\bar{\gamma} \equiv \sum_{s=1}^S n_s \gamma_s / \sum_{s=1}^S n_s$  is the population-weighted average distance between the hub and spokes. According to (8), we obtain Lemma 1:

#### Lemma 1

*The transit fee of the hub and the airport fee of spoke airports are strategic substitutes.*

For spoke passengers, airport services at the hub and each spoke are complementary goods. Therefore, if one airport increases its fee, the other airport has to decrease its fee.

By solving (8), we obtain the equilibrium airport fees as

$$a_d = \frac{1 - c}{2}, \quad (8.1)$$

$$a_t = \frac{1 - (1 + \bar{\gamma})c}{3}, \quad (9.1)$$

$$a_s = \frac{1 - c}{3} + \frac{1}{6}c(\bar{\gamma} - 3\gamma_s). \quad (9.2)$$

### 3.3. Pricing Strategies of Private Airports

In this subsection, we discuss pricing strategies by focusing on the distance. We start with airport fees of spoke airports. Hereafter, *Airport*  $s'$  is farther from the hub than *Airport*  $s$ , that is,  $\gamma_{s'} > \gamma_s$ . From (9.2), we obtain

$$\begin{aligned} a_s - a_{s'} &= \frac{c}{6}(\bar{\gamma} - 3\gamma_s) - \frac{c}{6}(\bar{\gamma} - 3\gamma_{s'}) \\ &= \frac{c}{2}(\gamma_{s'} - \gamma_s) > 0. \end{aligned}$$

This result is summarized in Proposition 1.

**Proposition 1**

*Airport fees of the spoke airport decreases as the distance to the hub,  $\gamma_s$ , increases.*

Demand for connecting flights decreases and becomes more elastic as the distance between a spoke airport and the hub increases because airfares become higher due to the airline's higher operating cost. Therefore, the spoke airport lowers its airport fee to boost demand. This result explains the fitted line in Figure 2. When the distance to the hub is long, the spoke airport chooses the lower airport fee, which offsets the higher airfare and increases the demand.

We move to pricing strategies of the hub airport and investigate the discount for transit passengers. According to (8.1) and (9.1), we obtain the ratio of the transit fee to departing fee as follows:

$$\frac{a_t}{a_d} = \frac{2}{3} - \frac{2c}{3(1-c)}\bar{\gamma}. \quad (10)$$

Differentiating (10) with respect to  $\bar{\gamma}$ , we obtain Proposition 2.

**Proposition 2**

*The ratio of the transit fee to the departing fee decreases as the weighted average distance,  $\bar{\gamma}$ , increases.*

The hub lowers its transit fee and compensates for higher airfare of spoke routes to attract more transit passengers when spoke airports are located far from the hub. On the other hand, the departing fee is independent from the location pattern of spoke airports. Therefore, the transit fee gets relatively small compared to the departing fee as the average distance becomes large. Note that in Figure 1, the discount ratio of MAD is the lowest among the five largest airports. This can be interpreted as follows. Since MAD locates at the fringe of Europe compared to the other four airports, the operator of MAD discounts the transit fee more than the others to attract more transit passengers from spoke airports.

**4. Welfare Analysis**

This section clarifies the effect of distance to the hub upon the social welfare for each spoke route. To deal with this problem, we designate *Route s* as the route from *Airport s* to the foreign country via the hub. We define the social welfare for *Route s* as the gross consumer benefit minus the social cost.

$$W_s = \frac{1}{2}(1 + p_s + a_t + a_s) d_s - (1 + \gamma_s)cd_s. \quad (11)$$

The first term is the lower part of the inverse demand function and the second term is the operating cost. The social welfare in the equilibrium is <sup>4</sup>

$$W_s^* = \frac{1}{288}(21X_s + Y)(3X_s - Y)n_s. \quad (12)$$

Here,  $X_s = 1 - c - c\gamma_s$  and  $Y = 1 - c - c\bar{\gamma}$ . Since we consider the case of fixed airline network

<sup>4</sup> Detailed process of the derivation is summarized in Appendix A.



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in this paper, demand should be positive for all routes. Thus,  $X_s$  is positive for all  $s$  and then  $Y > 0$ . At the optimum, airfare should be equal to the airline's marginal cost, and airport fees should be zero. Therefore, the social welfare at the optimum,  $W_s^o$ , is <sup>5</sup>

$$W_s^o = \frac{1}{2} X_s^2 n_s. \quad (13)$$

The welfare loss is  $W_s^o - W_s^*$ , and we define the welfare loss ratio on *Route s* as

$$\begin{aligned} \theta_s &\equiv \frac{W_s^o - W_s^*}{W_s^o} \\ &= \frac{1}{144} \left( 81 + 18 \frac{Y}{X_s} + \frac{Y^2}{X_s^2} \right). \end{aligned} \quad (14)$$

This ratio indicates the degree of market distortion. A large  $\theta_s$  means large welfare loss and large market distortion.

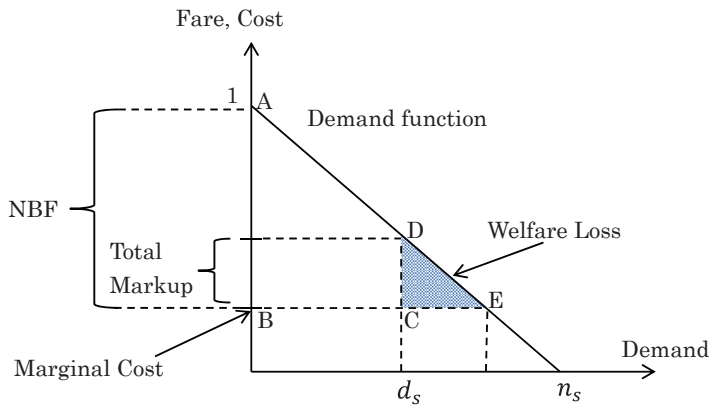
To analyze the relationship between the welfare loss and the distance, let us compare the two spoke airports,  $s$  and  $s'$  ( $\gamma_{s'} > \gamma_s$ ). From (14), we can state

$$\theta_s - \theta_{s'} = \frac{1}{144} \left[ 18 \left( \frac{1}{X_s} - \frac{1}{X_{s'}} \right) Y + \left( \frac{1}{X_s^2} - \frac{1}{X_{s'}^2} \right) Y^2 \right] < 0.$$

Since,  $\gamma_{s'} > \gamma_s$ ,  $X_{s'} = 1 - c - c\gamma_{s'} < X_s = 1 - c - c\gamma_s$ : therefore,  $\theta_s - \theta_{s'} < 0$ . From this, we obtain Proposition 3.

### Proposition 3

*The welfare loss ratio,  $\theta_s$ , increases as the distance between the hub and spoke,  $\gamma_s$ , increases.*



**Figure 4: Welfare Loss for Route s**

<sup>5</sup> See Appendix A for the derivation of these social welfare functions.

This result is derived from the hub's transit fee which is identical for all transit passengers. To clarify this mechanism, we define the “Net Benefit of the First trip ( $NBF_s$ )” and the “Total Markup ( $TM_s$ ).”  $NBF_s$  captures the net social gain of the first trip along *Route s*, which is computed as the highest willingness to pay (equal to unity) minus marginal cost of the flight operation,  $(1+\gamma_s)c$ . That is,  $NBF_s = 1 - (1+\gamma_s)c$ .  $TM_s$  captures the aggregate private gains of the airline, the hub and *Airport s*: that is,

$$\begin{aligned} TM_s &= [p_s - (1 + \gamma_s)c] + a_t + a_s = \frac{1 + a_t + a_s - (1 + \gamma_s)c}{2} \\ &= \frac{1 - (1 + \bar{\gamma})c}{12} + \frac{9\{1 - (1 + \gamma_s)c\}}{12} = \frac{Y + 9X_s}{12}. \end{aligned} \quad (15)$$

In Figure 4, the area CDE is the welfare loss and the area ABE is the social welfare at the optimum. Therefore, according to Figure 4, the welfare loss ratio is written as  $\theta_s = (TM_s/NBF_s)^2$ . While both  $TM_s$  and  $NBF_s$  are decreasing in  $\gamma_s$ , the decrease of  $TM_s$  is less significant than  $NBF_s$  due to the identical transit fee at the hub. Therefore,  $\theta_s$  is increasing in  $\gamma_s$ .

## 5. Discriminatory Airport Fee Policy

Proposition 3 shows that the relative welfare loss is increasing with the distance to the hub due to the uniform transit fee at the hub. To avoid the welfare loss due to uniform pricing for transit passengers, we consider the case where the hub can set its transit fee for each spoke route separately according to the demand elasticity. We call this case “discriminatory fee case.” In this case, the hub's revenue maximizing problem is reduced to maximize the fee revenue for each route. That is,

$$\max_{a_{t,s}} a_{t,s} d_s.$$

Here,  $a_{t,s}$  is the transit fee for *Route s* passengers. The best response is

$$a_{t,s}(a_s) = \frac{1 - (1 + \gamma_s)c - a_s}{2}.$$

Using the spoke's best response in (8.3), we obtain the transit fee as

$$a_{t,s}^d = a_s^d = \frac{1 - (1 + \gamma_s)c}{3}.$$

In the discriminatory fee scheme,  $TM_s^d$  is computed as:

$$TM_s^d = [p_s - (1 + \gamma_s)c] + a_{t,s}^d + a_s^d = \frac{5[1 - (1 + \gamma_s)c]}{6} = \frac{5X_s}{6}. \quad (16)$$

In contrast, the total markup under the uniform fee scheme,  $TM_s^u$ , is computed in (15). In comparison of these two,

$$TM_s^u - TM_s^d = \frac{Y}{12} + \frac{9X_s}{12} - \frac{5X_s}{6} = \frac{c(\gamma_s - \bar{\gamma})}{12}.$$

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This indicates that, for the routes where  $\gamma_s > \bar{\gamma}$ , the discriminatory fee scheme improves the economic welfare. This is because, in these routes, the discriminatory fee scheme results in the airport fee payments reduction<sup>6</sup> and the lower total mark up. In contrast, due to the rise in the airport fee payments, the economic welfare of the routes for  $\gamma_s < \bar{\gamma}$  is decreased when the discriminatory fee scheme is introduced.

Next, we focus on change in the welfare loss of the entire network. Because the welfare loss for each route is expressed as the triangle CDE in Figure 4, the loss for each is calculated as  $n_s TM_s^2/2$ . Aggregating the loss for all routes, the differential in the welfare loss of the entire network under the two alternative fee schemes is computed as:<sup>7</sup>

$$\Delta WL = \sum_{s=1}^S \frac{n_s [(TM_s^d)^2 - (TM_s^u)^2]}{2}. \quad (17)$$

If this sign is negative, the discriminatory fee scheme is more efficient than the uniform scheme; that is, the discriminatory fee scheme improves the economic welfare.

Although the sign of (17) may depend on the difference in the aggregate demand between the two alternatives, it is difficult to derive a clear result without assuming the population distribution. Therefore, we focus on the case where all spoke cities have the same population, that is,  $n_s = n$ . We rewrite (17) as:

$$\Delta WL = -\frac{1}{2885} n c^2 \sigma^2 < 0, \quad (18)$$

where  $\sigma^2$  is the variance of  $\gamma_s$ .<sup>8</sup> This result is summarised as follows:

#### **Proposition 4**

*When all the spoke cities have an identical population size, the discriminatory fee scheme is more efficient than the uniform scheme in terms of the entire welfare.*

As shown in Proposition 4, when all the spoke cities have an identical population size, the policy maker can improve social welfare by allowing hub airports to discriminate passengers in setting airport fees. However in reality, price discrimination is banned in many countries. For example, the EU Airport Charges Directive (2009/12/EC) prohibits differentiated fees to airlines using the same service. In the US, airports are compelled to offer same fees for same service by 2013 FAA's Policy Regarding Airport Rates and Charges. In some situation, however, Proposition 4 states that the uniform fee scheme harms the economic welfare.

<sup>6</sup> The differentials in the fees incurred by transit passengers in two cases are computed as:

$$a_t^u - a_{t,s}^d = \frac{1}{3} (\gamma_s - \bar{\gamma}) c,$$

$$a_s^u - a_s^d = \frac{1}{6} (\bar{\gamma} - \gamma_s) c.$$

Superscripts  $u$  and  $d$  indicate the uniform fee and the discriminatory fee cases, respectively. Also note that the fees under the uniform case (with the superscript  $u$ ) are derived as in (9).

<sup>7</sup> Since, under the two alternative fee schemes, the hub passengers incur the same level of airfare and airport fee, the loss at the hub airport remains at the same level; therefore, we ignore the change in the loss at the hub.

<sup>8</sup> See Appendix B for derivation of (18).

## 6. Conclusion

In this study, we analyzed airport pricing in an asymmetric hub-spoke network and obtained three results. First, the airport fees of a spoke airport decrease as the distance to the hub increases. This is because the demand from the spoke airport gets relatively smaller as the distance between the spoke and the hub increases, due to the high operating cost and airfare. Second, the ratio of the transit fee to the departing fee diminishes as the weighted average distance increases. Demand of a spoke route is a decreasing function of the distance. Therefore, the hub lowers its transit fee in attempt to boost the demand for transit services when spoke airports locate farther from the hub. Third, the welfare loss ratio increases as the distance between the hub and spoke increases. The mark-up ratio of a long spoke route is large due to the identical transit fee. Due to the large mark-up ratio, the welfare loss ratio also becomes large. Moreover, we showed the possibility that the discriminatory fee scheme improves the social welfare.

We need to extend our model in two aspects. First, we should establish a multi-hub model. It is often observed that some large airports compete for hub positions. Such competitions lead to discounting of airport fees. Second, we should consider airport groups and alliances among airports. If some airports are in one group or operated by a parent company, airport operators try to maximize the total profit of their group or company.

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## Appendix A: Derivation of social welfare

(i) The social welfare in the equilibrium

Plugging (1.2) into (11), we obtain

$$W_s = \left[ \frac{1}{2}(1 + p_s + a_t + a_s) - (1 + \gamma_s)c \right] (1 - p_s - a_t - a_s)n_s. \quad (\text{A. 1})$$

Plugging (6.2) into (A.1),

$$W_s = \frac{1}{8}[3 - 3(1 + \gamma_s)c + a_t + a_s][1 - (1 + \gamma_s)c - a_t - a_s]n_s. \quad (\text{A. 2})$$

Finally, substituting (9.1) and (9.2) into (A.2),

$$\begin{aligned} W_s^* &= \frac{1}{288}(22 - 22c - 21\gamma_sc - \bar{\gamma}c)(2 - 2c - 3\gamma_sc + \bar{\gamma}c)n_s \\ &= \frac{1}{288}(21X_s + Y)(3X_s - Y)n_s. \end{aligned} \quad (\text{A. 3})$$

Here,  $X_s = 1 - c - c\gamma_s$  and  $Y = 1 - c - c\bar{\gamma}$ .

(ii) The social welfare at the optimum condition

At the optimum,  $a_t = a_s = 0$  and  $p_s = (1 + \gamma_s)c$ . Hence, the demand at the optimum is

$$d_s = n_s[1 - (1 + \gamma_s)c]. \quad (\text{A. 4})$$

Plugging (A.4) into (11), we obtain the welfare function at the optimum as

$$\begin{aligned} W_s^o &= \frac{1}{2}(1 - c - c\gamma_s)^2n_s \\ &= \frac{1}{2}X_s^2n_s. \end{aligned}$$

## Appendix B: Comparison of two airport fee schemes

The difference of the welfare loss under both schemes is

$$\begin{aligned}\Delta WL &= \frac{1}{2}n \sum_s [(TM_s^d)^2 - (TM_s^u)^2] \\ &= \frac{1}{2}n \sum_s (TM_s^d + TM_s^u)(TM_s^d - TM_s^u).\end{aligned}\tag{B.1}$$

Here,

$$\begin{aligned}TM_s^d + TM_s^u &= \frac{1}{12}(20 - 20c - c\bar{\gamma} - c\gamma_s), \\ TM_s^d - TM_s^u &= \frac{1}{12}c(\gamma_s - \bar{\gamma}).\end{aligned}$$

Substituting them into (B.1), we obtain

$$\begin{aligned}\Delta WL &= \frac{1}{288}nc \sum_s [(20 - 20c - c\bar{\gamma} - c\gamma_s)(\gamma_s - \bar{\gamma})] \\ &= \frac{1}{288}nc \sum_s [-c\gamma_s^2 + 20(1 - c)\gamma_s + c\bar{\gamma}^2 - 20(1 - c)\bar{\gamma}] \\ &= \frac{1}{288}nc \left[ -c \sum_s \gamma_s^2 + 20(1 - c) \sum_s \gamma_s + Sc\bar{\gamma}^2 - 20S(1 - c)\bar{\gamma} \right].\end{aligned}\tag{B.2}$$

Because  $n \equiv n_1 = n_2 = \dots = n_S$ , we rewrite the weighted average distance as

$$\bar{\gamma} = \frac{\sum_s \gamma_s}{S} \Leftrightarrow \sum_s \gamma_s = S\bar{\gamma}.$$

We simplify (B.2) as

$$\begin{aligned}\Delta WL &= \frac{1}{288}nc \left( -c \sum_s \gamma_s^2 + Sc\bar{\gamma}^2 \right) \\ &= \frac{1}{288S}nc^2 \left( -\frac{\sum_s \gamma_s^2}{S} + \bar{\gamma}^2 \right) \\ &= -\frac{1}{288S}nc^2\sigma^2 < 0,\end{aligned}$$

where  $\sigma^2 \equiv \left( \frac{\sum_s \gamma_s^2}{S} - \bar{\gamma}^2 \right) > 0$  is the variance of  $\gamma_s$ .